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# Scholarly Collaboration Networks at the Naval Postgraduate School

Gregory A. Miller, LTC Scott M. Moore, Paul T. Beery, and Gary W. Parker

**Abstract**—This paper analyzes faculty scholarly collaboration networks at the Naval Postgraduate School (NPS). A brief description of the mission and organization of NPS provides background. The source of the network data is described, and the process of data extraction and formatting is explained. Measures of papers, authors, collaborations, and unique collaborators are presented at the department level and university-level. Results also include network metrics like mean path length, diameter, component number and size, clustering coefficient, degree distribution, and betweenness. Statistical analysis quantifies similarities and differences between departments. The nature of inter-department collaboration is described. Several techniques for graph visualization support the numerical analysis. Expected results include the nature of components within departments and the university as a whole, degree and component distributions, and mean values for authors per paper and papers per author. Unexpected results include the absence of a giant component in the university graph and very high clustering coefficients.

**Index Terms**—NPS, scholarly collaboration, networks, metrics

## I. INTRODUCTION

Social networks are collections of people who have some relationship to each other. Social networks are typically represented as graphs with people as nodes (vertices) and their relationships as links (edges). The nature of the relationships (e.g. influences/influenced by, friendship, supervises/works for) are defined by the person studying such interactions. A scholarly collaboration network (SCN) is a special case of social networks. Here, researchers

share a link by virtue of having worked together in producing some article, paper, or presentation. This is an accepted definition of relationship: co-authorship. This precise definition allows the unambiguous construction of a network based on available reports and databases dedicated to archiving or summarizing work in a given field or at a given institution. Studying collaboration and co-citation networks is not new. An early thorough study based on databases of biomedical research, theoretical physics and computer science was completed by Newman (2001). Additionally, collaboration networks for knowledge creation and transmission in industry were studied by Schelling and Phelps (2007).

This paper investigates scholarly collaboration networks (SCNs) at the Naval Postgraduate School (NPS) in Monterey, CA. These SCNs represent relatively large real-world networks of human collaborators. Analysis includes identifying nodes with the highest degree, degree distribution histograms, mean degree, mean shortest path length, betweenness centrality, clustering, and diameter. Analysis of these measures allows us to identify the most ‘collaborative’ faculty, the most ‘collaborative’ departments, and to describe inter-department relationships. This pilot study is the first such quantitative analysis of SCNs at NPS. Our objectives in this study include determination of the adequacy of data sources and documentation of our procedures.

Academic rank, military rank, and titles for faculty identified by name have been suppressed for brevity. Although technically NPS is a school composed of schools, the term “university” is used in this paper to differentiate when making NPS-wide references as compared to individual department, school, or institute references.

## II. BACKGROUND

In 1945, Congress established the Naval Postgraduate School, “... to provide advanced instruction and professional and technical education and research opportunities for commissioned officers of the naval service” (U.S. Code, 1945).

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The mission of NPS is to

“... enhance the combat effectiveness of the Navy and Marine Corps by conducting and directing advanced education of commissioned officers, and provide such other technical and professional instruction as may be prescribed to meet the needs of the Naval Service . . . to sustain academic excellence, foster and encourage a program of relevant and meritorious research.” (OP-NAVINST, 2007)

Today, NPS has grown from a technically-oriented institution with only engineering courses into a diverse institution serving the broader needs of the Joint services with stabilization and reconstruction along with homeland defense (NPS, 2010). The school has over 40 programs of study including electrical and computer engineering, mechanical and aeronautical engineering, systems engineering, space systems and satellite engineering, physics, oceanography, meteorology, applied mathematics, computer science, operations research, business and public policy, international relations, and other disciplines, all with an emphasis on military applications (NPS, 2010). NPS is the nation’s research university for the Department of Defense.

### III. METHODOLOGY

#### A. Data Source

Every year, the NPS Research and Sponsored Programs Office (RSPO) publishes a Summary of Research report (NPS, 2011). The report provides a brief overview of each department on campus, a listing of faculty and a summary of research activities. It also lists journal articles, technical reports, conference presentations, patents, contributions to books, and practically every form of publication completed by the faculty at NPS. The Summary of Research report is organized by school and by department as follows:

- School of International Graduate Studies (SIGS)
  - Defense Resources Management Institute (DRMI)
  - Department of National Security Affairs (NSA)
- Graduate School of Operational and Information Sciences (GSOIS)
  - Department of Computer Science (CS)
  - Department of Defense Analysis (DA)
  - Department of Information Science (IS)
  - Department of Operations Research (OR)
- Graduate School of Engineering and Applied Science (GSEAS)
  - Department of Applied Mathematics
  - Department of Electrical and Computer Engineering (ECE)
  - Department of Mechanical and Aerospace Engineering (MAE)
  - Department of Meteorology
  - Department of Oceanography
  - Department of Physics
  - Department of Systems Engineering (SE)
  - Space Systems Academic Group (SSAG)
- Graduate School of Business and Public Policy (GSBPP)

The data in the Summary of Research report is based on individual faculty activity reports (FARs) submitted annually by each faculty member. These FARs include instructional, research, and service activities for the calendar year of the report. The research activities are rolled up at the department level, where duplicate reporting of publications is eliminated. That is, if Jones and Smith are in the same department and co-authored a paper, they would have each listed it on their respective FAR. When their department consolidates their individual FARs into a single department-level report, that one paper would only be listed once. The RSPO then consolidates the reports from the departments to create a single document for the entire university.

There are some other points to be made to have a more complete understanding of the data. In their personal individual reports, faculty members include publications they wrote on their own (without collaborators), those written with other NPS faculty, and those written with members of other institutions. The affiliation of all co-authors are not reported. So, even though there are about 730 NPS faculty, there are 1002 unique names in the report. That also led to duplicate reporting of papers with authors from more than one department. While such duplication is eliminated at the level of the department, there is no mechanism to prevent the same paper from appearing in several different departments’ sections. The result of this is that, with two exceptions (the Meteorology and Oceanography departments), the networks for each department include authors from other departments. Additionally, the departments used their own style for listing authors. Some used first name and last name while others used initials and last name. For purposes of this study, using only last name with first initial in the first pass through the report provided some standardization. The problem of distinguishing authors with the same

name was anticipated, and potential duplications were identified by using sorting routines in spreadsheet software. The addition of middle initials and complete first names (in a few cases) permitted unique identifying names for all authors. It should also be noted the authors of this paper know many of the subjects of this study, which made identifying distinct names more manageable.

### B. Study Scope

To bound the study, certain decisions were made early in the process to ensure consistency when comparing data across several organizations.

- In addition to the departments and organizations listed above, there are also several other institutes and centers at the university. Since some members of these institutes and centers hold joint appointments along with departmental positions, it was decided to limit the data considered to the listed academic departments.
- Because we were interested in collaboration, only publications with more than one author were included.
- Only journal articles and conference publications would be included (books, patents, certain technical reports and other documents were not).
- Only one year was used (calendar year 2010) to limit the size of the data sets involved for this pilot study.
- Every component has at least one NPS faculty author.

### C. Data Extraction and Formatting

The contents of the report are considered to be the most reliable and complete catalog of publications generated at NPS. Therefore, we can have a great deal of confidence in any collaboration network based on the data. Unfortunately, it does not exist as an easily accessible database. It is assembled using commercial word processing software and then distributed as a Portable Document Format (PDF) file. The process of extracting the data from the PDF format was somewhat time-consuming, but it was bounded and finite. The authors' names for each paper were placed in adjacent cells on a single row in a Microsoft Excel spreadsheet file, with one tab dedicated to each department. From that, an incidence matrix was constructed, and then an adjacency matrix for each department was created. Finally, an incidence matrix and an adjacency matrix for the entire university were assembled.

## IV. RESULTS

### A. Adjacency Matrix Representation

The non-zero elements of the adjacency matrix for the university are shown in Figure 1. Because the

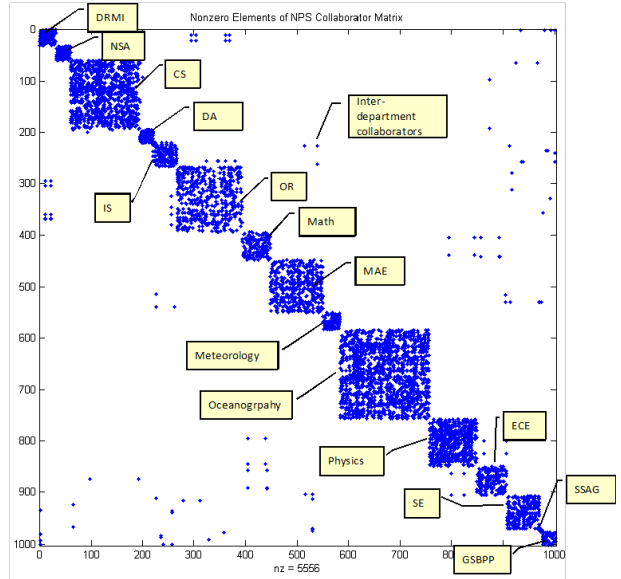


Figure 1. Non-zero elements of the adjacency matrix for NPS SCN in 2010. The high density of non-zero elements along the main diagonal represents departments. The isolated off-diagonal points represent inter-departmental collaborators.

adjacency matrix for the university as a whole was constructed from the department matrices, it was easy to identify the departments and to identify where the inter-department collaborations were taking place. For instance, the few points marked by the “Inter-department collaborators” call-out in Figure 1 indicate interaction between members of the MAE Department and IS Department.

### B. Authorship Measures

Table I summarizes authorship statistics of the networks. The mean papers per author and mean authors per paper were assembled from the incidence matrices. The mean collaborations per author counts the number of collaborations each author had – the total number of collaborations across all his papers. The lines for unique collaborators only counts other authors once, regardless of the number of papers jointly worked. That is, if Smith worked with Jones and Adams on three different papers, Smith would count that as six collaborations, but only two unique collaborators. Thus, the weighted adjacency matrices provide the number of collaborations and the

Table I  
PAPER AUTHORSHIP MEASURES

School	Department	Total papers	Total authors	Mean papers/author	Mean authors/paper	Mean collaborations/author
SIGS	DRMI	22	36	1.61	2.76	4.17
	NSA	8	29	1.03	4.29	7.31
GSOIS	CS	60	138	1.73	4.05	9.36
	DA	9	26	1.27	4.12	6.15
	IS	38	53	2.13	3.05	6.00
	OR	84	132	1.91	3.00	4.85
GSEAS	Math	37	60	1.73	2.89	3.67
	ECE	35	63	1.70	3.15	4.30
	MAE	71	106	2.39	3.61	7.96
	Met	34	34	3.06	3.06	7.24
	Ocean	55	172	1.53	4.78	9.11
	Physics	49	97	2.03	4.02	8.93
	SE	32	70	1.50	3.28	4.11
	SSAG	3	7	1.86	4.33	6.57
GSBPP	GSBPP	24	35	1.83	2.67	3.49
NPS Total		504	1002	1.90	3.51	7.10

unweighted matrices provide the number of unique collaborators. The reader is reminded that the process of reporting and consolidating allows for a single paper to be counted in more than one department. For this study, that duplication was eliminated in the “NPS Total” column, but the original listings were kept on a per-department basis.

Elimination of duplicated papers allowed for a more in-depth analysis of the authorship measures for the collaboration networks. Statistical hypothesis testing was proposed as a method for analyzing the dissimilarities between the NPS Departments with respect to mean number of papers per author and mean number of authors per paper. However, cursory analysis of intradepartmental variance indicated that the variance between each of the NPS Departments was heterogeneous for both measures, thereby prohibiting traditional statistical analysis methods (ANOVA, t-test). Due to the lack of communal consensus regarding testing for heterogeneity of variance, the statistical analysis package JMP provides an O’Brien, Brown-Forsythe, Levene, and Bartlett test for unequal variance. The results are summarized in Figure 2. Each test confirms that the variance for both

Tests for Unequal Variance		
Test	Prob > F Authors/Paper	Prob > F Papers/Author
O'Brien	0.0012	0.0130
Brown-Forsythe	<.0001	0.0019
Levene	<.0001	<.0001
Bartlett	<.0001	<.0001
Welch-ANOVA Results		
Measure	F Ratio	Prob > F
Authors/Paper	3.01	0.0012
Papers/Author	11.45	<.0001

Figure 2. Authorship measure analysis.

measures is unequal at a p-value of 0.01. Accordingly, a Welch-ANOVA was conducted to test for equality

of means between departments. The Welch-ANOVA for both measures indicated inequality of means. The analysis was expanded to compare the mean number of papers per author and the mean number of authors per paper to the respective NPS averages. Due to the inequality in variances and sample sizes, a Welch-t-test was conducted for each of the departments for each of the measures. The results are presented in Table II. The majority of the results from the Welch-

Table II  
ANALYSIS OF DEVIATION FROM UNIVERSITY AVERAGES

Deviation from University Average (Number of Authors per Paper)				Deviation from University Average (Number of Papers per Author)			
Department	p-value	Department	p-value	Department	p-value	Department	p-value
DRMI	0.011	MAE	0.645	DRMI	0.392	MAE	0.043
NSA	0.656	Met	0.024	NSA	0.000	Met	0.249
CS	0.092	Ocean	0.007	CS	0.626	Ocean	0.010
DA	0.443	Physics	0.319	DA	0.001	Physics	0.347
IS	0.089	SE	0.403	IS	0.325	SE	0.126
OR	0.002	SSAG	0.348	OR	0.786	SSAG	0.733
Math	0.010	GSBPP	0.001	Math	0.718	GSBPP	0.590
ECE	0.069			ECE	0.769		

t-test’s were intuitive. Those departments with the largest absolute differences for a given measure between their department and the school average were identified as statistically significant. However, one result of the tests was particularly interesting. The largest absolute difference between mean number of papers per author and the school average (3.06 to 1.90) is in the Meteorology Department, and was not statistically significant. Examination of the data shows that the Meteorology Department’s variance for that measure is 34.51. The extreme variance is due to a single author who participated in 34 collaborative papers. Removal of this author reduces the department average authorship from 3.06 to 2.15 and reduces the variance from 34.51 to 4.82. However, given the nature of this analysis, removal of such a node is inappropriate and the impact of the node will be further discussed later in this paper.

### C. Collaboration Measures

Table III summarizes the paper collaboration statistics. The mean collaborations per author counts the number of collaborations each author had – the total number of collaborators across all his papers. The lines for unique collaborators only count other authors once, regardless of the number of papers jointly worked. The highest number of collaborations was in the Meteorology Department for Montgomery who had 70 collaborations, of which only 33 were unique collaborators. The highest number of unique collaborators was in the Oceanography Department for Maslowski with 35 unique collaborators.

Table III  
PAPER COLLABORATION STATISTICS

School	Department	Mean collaborations/author	Most collaborations (#)	Mean unique collaborators	Most unique collaborators (#)
SIGS	DRMI	4.17	Hansen, J. (10)	3.89	Amara, J. (9)
	NSA	7.31	Ear, S. (14)	7.31	Ear, S. (14)
GSOIS	CS	9.36	Irvine, C. (37)	7.52	Blais, C. (24)
	DA	6.15	Denning, D. (10)	5.69	Denning, D. (10)
	IS	6.00	Hutchins, S. (30)	3.32	Nissen, M. (14)
	OR	4.85	Alderson, D. (29)	4.00	Alderson, D. (18)
GSEAS	Math	3.67	Stanica, P. (19)	3.12	Stanica, P. (13)
	ECE	4.30	Butler, J. (16)	3.27	Butler, J. (10)
	MAE	7.96	Kaminer, I. (52)	4.45	Kwon, Y. (21)
	Met	7.24	Montgomery, M. (70)	4.35	Montgomery, M. (33)
	Ocean	9.11	Colosi, J. (39)	8.24	Maslowski, W. (35)
	Physics	8.93	Colson, W. (58)	6.66	Colson, W. (28)
	SE	4.11	Madachy, R. (23)	3.60	Madachy, R. (17)
	SSAG	6.57	Newman, J. (10)	3.71	Newman, J. (6)
GSBPP	GSBPP	3.49	Apte, U. (10)	2.40	Apte, U. (6)
NPS	Total	7.10	Montgomery, M. (70)	5.55	Maslowski, W. (35)

Table IV  
NETWORK COMPONENT MEASURES

School	Department	Diameter	Mean shortest path length	Number of components	Clustering Coefficient
SIGS	DRMI	5	2.17	5	0.81
	NSA	2	0.89	6	0.99
GSOIS	CS	4	1.71	9	0.83
	DA	2	0.84	5	0.98
	IS	2	1.28	9	0.67
	OR	5	2.20	13	0.58
GSEAS	Math	6	2.36	6	0.50
	ECE	2	0.95	13	0.77
	MAE	4	1.76	13	0.59
	Met	2	1.76	1	0.25
	Ocean	9	3.64	6	0.73
	Physics	3	1.64	7	0.76
	SE	2	1.27	12	0.63
GSBPP	SSAG	2	1.04	1	0.80
	GSBPP	4	1.32	9	0.71
NPS	Total	13	4.23	89	0.73

#### D. Network Component Measures

Table IV summarizes measures of the components for each department within NPS, and a total for NPS overall. The total number of components for NPS does not equal the sum of the components for the departments, because inter-department collaborations connect department components, reducing the overall number of NPS components. Figure 3 shows the distribution of component size over the entire NPS. There are a total of 89 components. Note that the total number of components is larger than the number of departments since most departments have multiple components. For example, Figure 4 is the collaboration network for the Systems Engineering Department, which shows typical structure. With one exception, the other departments follow a similar pattern of 3 or 4 larger components, each with 8 to 20 nodes and 8 to 10 smaller components, each with 2 to 4 nodes. From this, we can easily see some ‘central figures’ in this department: Madachy, Yakimenko, and Millar. Also, with a personnel listing for each department, it is relatively easy to identify collaborators from other departments: Russell, Osmundson, Bourakov, and Angelis, just to name

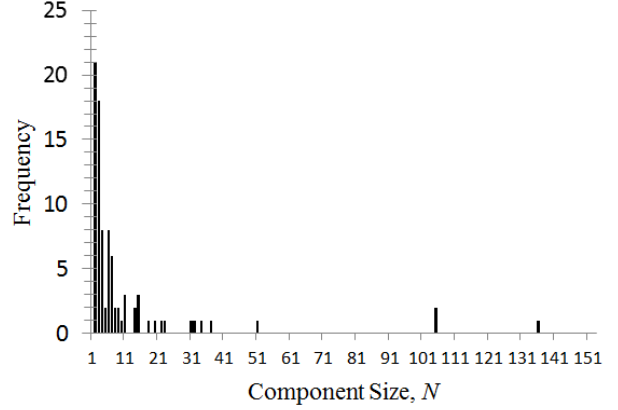


Figure 3. Component size distribution for NPS scholarly collaboration network in 2010. There are a total of 89 components.

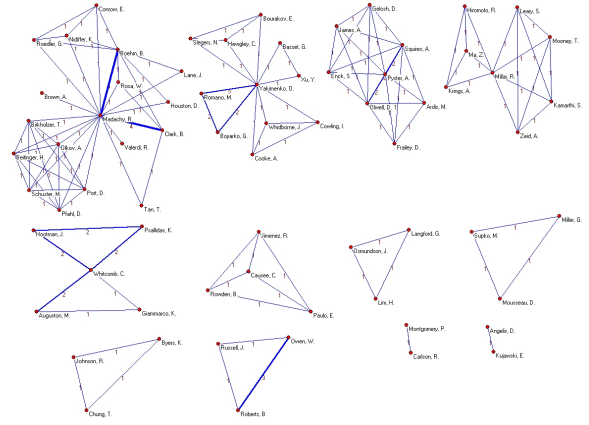


Figure 4. NPS Systems Engineering Department Graph

a few. Additionally, we can see collaborators from other organizations. Just to mention a few, Boehm is from the University of Southern California, Valerdi is from the Massachusetts Institute of Technology, Gelosh is from the Worcester Polytechnic Institute, and Pyster and Squires are from the Stevens Institute of Technology. Current and former students can also be identified: Hewgley, Causee, Jimenez, Rowden, Johnson, Lim, Mousseau, and Supko are examples. This result was somewhat expected. That is, we know that certain faculty members have shared interests and research programs that allow them to work in teams. Some of the teams are large and many are small. Students make up a number of non-NPS faculty collaborators. There is some variation in specifics across the departments, but the general layout is the same.

The one exception was the Department of Meteorology, shown in Figure 5. No other department consists of a single component. Montgomery co-authored all



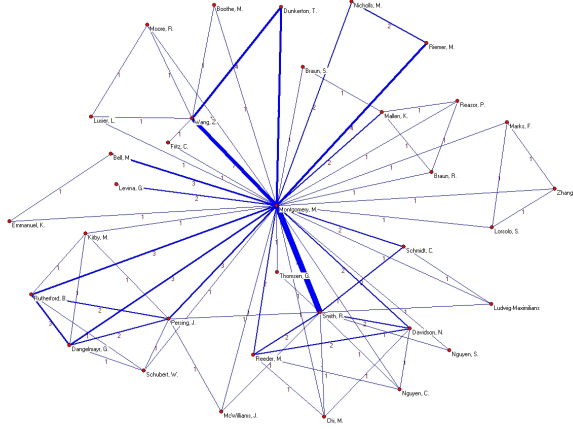


Figure 5. NPS Meteorology Department Graph

45 papers from his department in 2010. Some of the students here are Chi, Davidson, Fritz, Kirby, Levina, Nguyen, Nicholls, Schmidt and Schubert. The hub-and-spoke nature of this network helps to explain the low clustering coefficient. This visualization corroborates the earlier discussion of mean papers per author and mean authors per paper. Montgomery’s betweenness is not unusual compared to the rest of the university, and the betweenness measures of all of his collaborators are among the lowest.

Figure 6 shows the distribution of node degree over

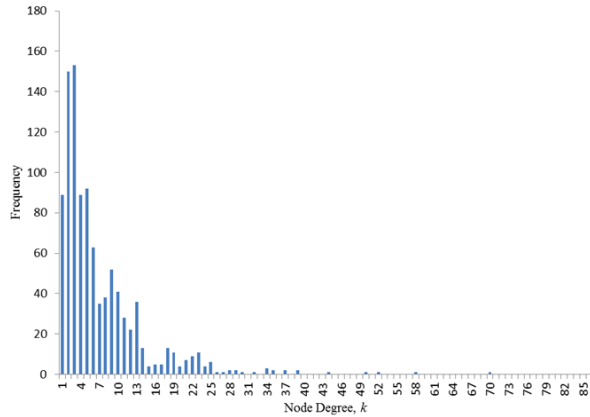


Figure 6. Node degree distribution for NPS scholarly collaboration network in 2010.

the entire NPS. It was expected that most nodes would be in the range of 2 to 5, since most scholarly papers involve collaborations in that range. It is interesting to note that a few nodes have high ( $> 40$ ) degree, and a very few have very high ( $> 50$ ) node degree. Given that the size of the largest component is 136 nodes, it is apparent that no giant component exists ( $136/1002=13.57\%$ ). While the nature

of the data may explain this finding, it does seem unusual in light of Newman, Watts, and Strogatz’s assertion that “Almost all networks found in society and nature seem to be well inside the region in which the giant component exists; networks with no giant components are rare” (Newman, 2002, p. 2569).

### E. Clustering Coefficients

The clustering coefficients of each department and the university as a whole were also calculated. The results are listed in the rightmost column of Table IV. These figures are consistent with the visualizations of those networks which indicate higher clustering than non-social networks. Compared to other scholarly collaboration networks (Newman, 2010), these numbers are quite high. One explanation is this is one relatively small institution with a very focused mission and limited number of sponsors. So, it is more likely to see clusters of authors around a set of related subjects.

### F. Betweenness Measures

The *betweenness* of a node is the number of shortest paths between pairs of nodes in the connected graph that pass through that node. In sociological terms a node with high betweenness but low node degree is called a *broker*. Table V shows the betweenness

Table V  
SELECTED AUTHOR BETWEENNESS MEASURES

Author	Degree	Betweenness	Component ID	Component Size
McDonald, M.	3	2700	2	105
Kang, K.	4	2695	2	105
McNab, R.	3	855	2	105
Meyer, T.	4	758	2	105
Melese, F.	4	303	2	105
Osmundson, J.	4	204	2	105
Lipow, J.	3	103	2	105

measure and node degree for selected authors in the component that includes authors from the IS, GSBPP, and DRMI departments. The authors were selected on the basis of having a high betweenness metric, and a node degree  $k_i \leq 4$ . McDonald and Kang’s measures indicate they occupy a bridging position or broker role between subcomponents. Figure 7 is a graphical representation of the 105-node component, with the authors in Table V shown in red. Note the single link between McDonald and Kang that connect the two subcomponents. A *leaf* node is a node with degree 1, the term being derived from nodes terminating branches in tree networks.

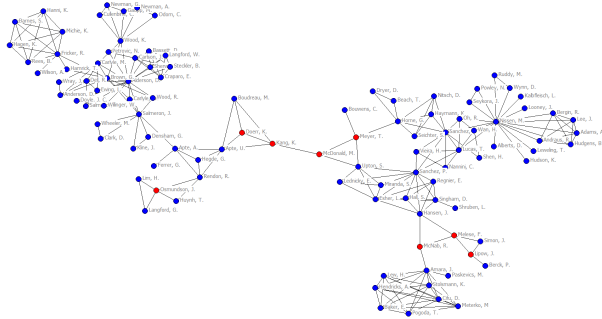


Figure 7. Collaborations spanning the 105-node component containing authors from the IS, GSBPP, and DRMI departments. Red nodes are the authors in Table IV. Note the bridging role played by McDonald and Kang between two subcomponents.

Other authors with high betweenness (Meyer and Lipow) have a single author or leaf node associated with them, meaning that every path connected to that author must pass through them.

### G. Inter-departmental Collaborators

Figure 8 shows a simplified graph denoting inter-

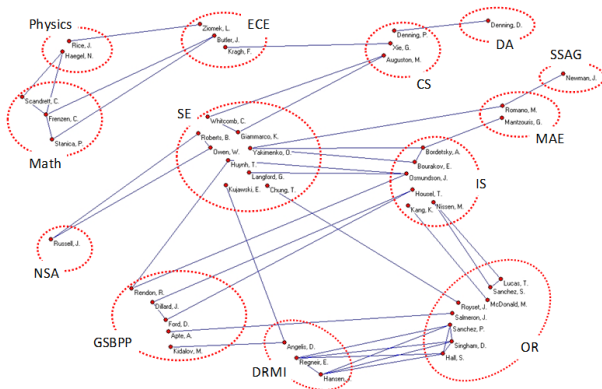


Figure 8. Inter-departmental collaborations in 2010.

departmental collaborators within the NPS faculty. Some connections between departments seem obvious based on the historic connections between their fields: MAE – SSAG, Physics – Math, Physics – ECE. Others are based on the mission of the departments. For instance, DRMI conducts research and education in the areas of analytical decision making and resources management for military officers and senior civilians in defense acquisition and operations. This includes management, economics, acquisition, decision theory, and risk analysis. Therefore, the connections with GSBPP and OR are expected. The

inter-disciplinary nature of the fields of systems engineering and of information science are also explanatory of the connections of the SE and IS Departments with other departments.

It should be noted that collaborations are based not only on shared research areas. They are also reflective of more personal and socially-relevant relationships. For example, married couples on campus produced several works: Oriti and Julian, D. Denning and P. Denning, N. Miller and Shattuck. Additionally, people who emigrated from the same country have worked together. For example, Cristi and Oriti are from Italy; Bordetsky, Yakimenko, Dobrokhodov, and Bourakov are from Russia. Scholarly work is a team sport: a social activity. That means social factors play an important role in research and experimentation. Trust relationships, competition, ambition, and emotion influence the process. Studying scholarly collaboration networks requires some understanding of those relationships to come to a deep understanding of their meaning.

Working with students on their theses and dissertations has always been a strong motivational factor for faculty collaboration. Many of the non-faculty collaborators are students. Knowledge creation through research equals learning, enriching students' experience at NPS. Co-authoring papers with students is considered an important aspect of mentoring students. The interests of students in these fields also contributes to otherwise unexpected collaborations. One example is Marine Corps Captain Joshua Dixon whose thesis "Integrating Cellular Handset Capabilities with Marine Corps Tactical Communications" brought together Kragh of ECE and Xie of CS (NPS, 2011).

## V. CONCLUSIONS

This pilot study demonstrated that meaningful data could be extracted from the Research and Sponsored Program Office's existing reports, and that the data could be formatted into matrices for quantitative analysis.

Analysis of network metrics produced some expected results. The mean numbers of authors per paper were between 1.5 and 3; the mean numbers of papers per author were between 2.5 and 4. Also expected was the structure of each department's network which included several large components and many small components (the one exception to this pattern was described). The departments naturally form communities within the graph of the entire university. However, inter-department collaboration leads to large



component formation that does not necessarily correspond strictly to department boundaries. Inter-department collaboration appears to result from the nature of the disciplines involved as well as the personalities of the faculty. We identified all inter-department collaborators across the university, and brokers (low degree, high betweenness) in a 105-node component.

Several of our results were unexpected. Departments exhibited higher than expected clustering coefficients, possibly due the number of papers with three or more authors. Inter-departmental collaboration was expected to result in a giant component, but the NPS network's largest component contains only 13.57% of the nodes. The absence of a giant component in the NPS networks might be due to a non-random distribution of inter-departmental links.

Given the availability of several years of publication data, much can be learned by further study and analysis of NPS SCNs. An alternative way of analyzing the data would be to construct bipartite graphs in which one type of node represents the authors involved and the other type of node represents the shared relationship (e.g., papers produced, parties attended, board or committee membership, stores frequented). The existing departmental incidence matrices could be used to map authors to papers, and results presented as 2-mode network graphs. Future work could explore the automation of data extraction and formatting to permit a more thorough analysis that includes several years of data. An analysis of several years of data would present a more complete picture that could identify long-term collaboration partnerships at NPS, or identify trends in the number of inter-departmental collaborations. A time-series view of the networks might also indicate the stability of SCN structures or how the networks change over time. Future work could compare NPS networks with those of other academic and research institutions, both military and civilian. Another area for possible future work is examining the level of student participation in research by identifying authors who were NPS students at the time of publication. A network generating algorithm based on a modified preferential attachment model could be developed for producing collaboration networks whose statistics more closely resemble those observed at NPS. For example, new inter-departmental links (representing collaborations) could be added with a higher probability between departments of similar disciplines (e.g. SE and OR, or Math and Physics departments), and with a very low probability between dissimilar departments (e.g. Physics and DRMI). The question

of whether a correlation exists between the size of research budgets and the level of scholarly collaboration might also be examined by analyzing multiple years of data on scholarly output.

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